Canadian microbolometer technology for future space missions

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ABSTRACT

This paper provides an overview of the microbolometer technology developed in Canada, including pixel engineering, readout electronics, and detector packaging. Design considerations are also presented for a two band LWIR radiometer intended for microsatellite-based demonstration of microbolometer technology.

INTRODUCTION

The use of uncooled microbolometers in space instruments such as infrared radiometers and earth sensors has received considerable attention in recent years. In Canada, the development of microbolometers started in 1995 under a collaborative agreement between the Canadian Space Agency, Defence R-D Canada, and INO. Driven by the requirements of space and defense applications, the technologies developed encompasses linear and focal plane arrays of resistive microbolometers, CMOS readout integrated circuits (ROIC), and detector packaging. This paper provides an overview of these technologies with emphasis on linear array technology for space applications. In addition, design considerations for a LWIR radiometer intended for microsatellite based demonstration of microbolometer technology will be presented.

TECHNOLOGY OVERVIEW

To date, the main focus of the technology developed in Canada has been resistive microbolometers. These consist of room temperature VO_2, VO_x, and YBaCuO semiconductors.[1, 2] There was no major effort devoted to amorphous Si or capacitive microbolometers.

At the pixel level, bolometer films are sputter deposited onto free standing Si_3N_4 microbridges that serve as thermal isolation structures. The bridges are built monolithically on Si wafer with embedded ROIC using surface Si micromachining. The gap between the bridge and wafer is defined by the thickness of sacrificial polyimide layer. This process is fully compatible with 1.5 and 0.8 μm CMOS technologies. The resistance of via contacts between the microbolometers and ROIC is less than 5 Ω. Figure 1 shows examples of bridge structures tailored to different application requirements. The standard bridge (Fig. 1*a*), 50x50 μm^2, has a thermal conductance ~ $4x10^{-7}$ W/K and time constant ~ 5 ms. This type of bridge is found typically in 160x120 focal planes of FLIR cameras. As the bolometric responsivity improves with better thermal isolation, the length of the supporting hinges was increased. The bridge with elongated hinges, as shown in Fig. 1*b*, sees its thermal conductance reduced to ~ $1.8x10^{-7}$ W/K. However, because its thermal capacity is not reduced as much, the resulting time constant is about twice that of the previous bridge. Lately, smaller bridges have been designed so as to increase the number of linear array pixels. Figures 1*c* and 1*d* show the 39 μm and 25 μm bridges with thermal conductances ~ $1.9x10^{-7}$ and $4.4x10^{-7}$ W/K respectively. In particular the hinges of the 25 μm bridge are placed under the bridge, resulting in fill factors better than 80%. At room temperatures, the temperature coefficients of resistance (TCR) of VO_2, VO_x, and YBaCuO microbolometers are respectively ~ 3, 2.5 and 2 %. Although VO_2 exhibits the largest value of TCR, it is less immune to substrate temperature drifts due to the strong temperature dependence of its TCR near the transition. The 1/f noise is more dominant in VO_x pixel than in YBaCuO pixel. It is, for instance, equal to the Johnson noise at 280 Hz in the former and at 30 Hz in the latter. The typical D* measured on 50x50 μm^2 pixel is $3x10^9$ cm.Hz$^{1/2}$/W for 10 μA bias and 30 Hz modulation.

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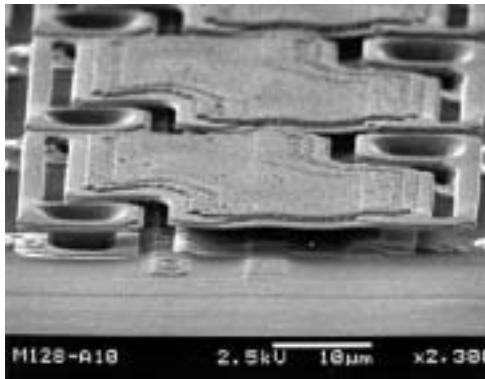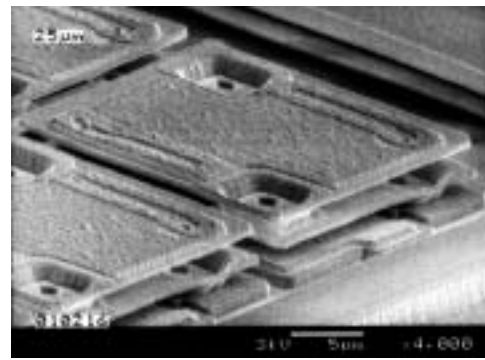
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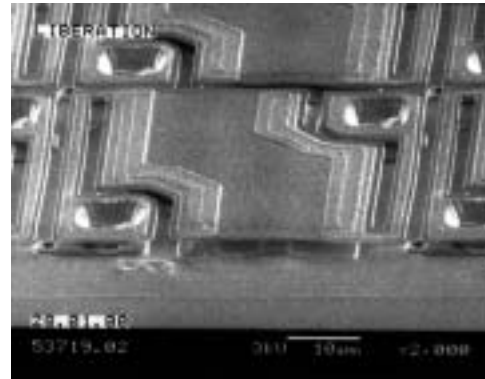
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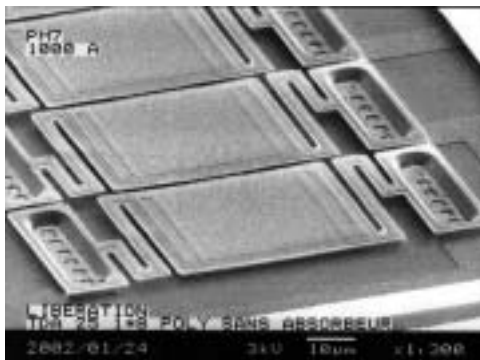
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Figure 1: *Examples of bridge structures for microbolometers: (a) standard 50 μm bridge; (b) bridge with elongated hinges for improved thermal isolation; (c) 39 μm bridge for high density linear array; (d) 25 μm bridge with underside hinges for large fill factor.*

ROICs have been developed for three linear arrays, 256x2, 256x40, and 512 x3, all suited for pushbroom scanning mode. The last two arrays were custom developed for an earth sensor[3] and a multispectral imager[4], the latter being intended for ESA's Earthcare mission. The 256x2 array comprises an active 256x1 array plus a parallel reference array. The array pixel consists of 50x50 μm^2 microbolometer on 52 μm pitch. The reference pixel provides coarse offset correction and temperature drift compensation. The pixels are read out sequentially or in arbitrary sequences using either dc or pulsed bias. The 256x40 array is a quasi linear array of 256 pixels, each containing of a series of 20 pairs of microbolometers (Fig. 2). The size and pitch of the microbolometers are identical to those of the 256x2 array. The microbolometers of each pair are connected in parallel and can be excluded from the series by closing the transistor switch across each pair. The mismatches between pixels can further be corrected by inclusion or exclusion of four Si resistors in series with the microbolometers in each pixel. The 24 transistor switches are programmed such that the output signals of the pixels can be matched within 0.01% over a temperature range of several degrees.[5] The pixels are addressed in random access mode and may be switched to either of two parallel output buses. These buses allow the array to be arranged in two parallel or sequential arrays or allow for differential measurement. The 512x3 array, currently under development, consists of three lines of 512 pixels with a 2 mm spacing. The signal in each line is integrated in parallel so that, when required, these lines would each collect radiation from a different spectral band. Because of the small interline spacing, the data for
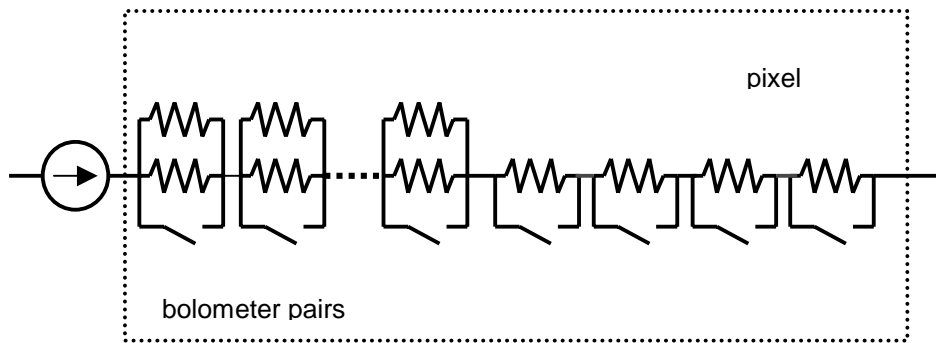
Figure 2: *Arrangement of microbolometer pairs and Si resistors in a pixel of the 256x40 array*

each spectral band may be obtained using a single broadband objective and dedicated filters for each band (in-field separation technique) without a large displacement of the field of view on the ground for each band. This reduces significantly the co-registration problem due to instability of satellite orientation. The ROIC of this array is implemented in an epitaxial process for increased immunity to radiation. The active, blind, and reference pixels, of 39 μm pitch, form the Wheatstone bridge circuit for offset correction and temperature drift compensation. The blind pixel incorporates a top mirror film so that it is thermally sensitive to Joule heating and substrate temperature change. The reference pixel consists of a bare microbridge (without bolometer) that is sensitive to substrate temperature change uniquely. Beside the linear arrays, a 160x120 focal plane array was also developed. The array pixel consists of 50x50 μm^2 microbolometer on 52 μm pitch. The pixel access can either be in sequential scanning or random access mode. In the latter mode the array may be used as a series of linear arrays by accessing certain rows only. This array, as the previous ones, contains also reference pixels for offset correction and temperature drift compensation.

In order to achieve good thermal isolation of the microbolometer, the devices are packaged in vacuum so as to minimize heat transfer from the bridge to heat sink. Typically, the diced device is mounted in a metal or ceramic leaded package using epoxy. Both packages are covered with transmissive infrared window made of Ge or ZnSe. The flat metal package has a footprint of 50x50 mm^2 and contains a side vacuum tube as a means to evacuate and seal off the package. The ceramic package has a footprint of 30x26 mm^2. Access to the latter package consists of a small leaded opening in the back of the package. The package is evacuated in a vacuum chamber. When the desired pressure is reached in the chamber, a laser beam is used to thermally dissolve the lead in the opening, sealing it off. Hermeticity can be achieved for at least four years in these packages without the need for getter refiring. Tests of vibration, shock, and temperature cycling showed compliance with MIL-STD-810 and MIL-STD-883 specifications. Some of the devices were exposed to 60 MeV proton irradiation (dose ~10^{12} cm^{-2}). The irradiated devices showed no measurable changes in resistance, responsivity, and noise.

RADIOMETER DESIGN

The Canadian Space Agency is currently planning a series of microsatellite based technology demonstration in view of providing Canadian industry with space heritage. The 512x3 array of microbolometers is among the candidates proposed for space experiments. To evaluate the performance of this device, its use for cloud temperature measurement from low earth orbits is being considered. The experiment will be performed in two spectral bands: 10.3-11.3 μm and 11.3-12.3 μm. The temperature difference between these bands can be used to discriminate ice cloud from water cloud on the basis of the

split window technique. Design considerations for a two-band instrument for this experiment are described in the following.

A radiometer with in-field separated bands appears to be the most compact instrument for the above purpose. The radiometer architecture implies the use of two lines of the 512x3 array behind a Ge optics, each with dedicated bandpass filter centered respectively at 10.8 and 11.8 µm. The third line is used as a reference for thermal drift compensation. The thickness of the filter substrate can be used as a parameter to correct the chromatic aberration of the optics. The device is operated in the pushbroom scanning mode. The spatial resolution that can be achieved in this mode is dictated by the data rate of the payload-to-computer interface. For instance, for direct data acquisition using the 300 kb/s RS-422 link, the resulting sampling interval for the 512x2 array of 15-bit pixels is 51.2 ms. Considering the equivalent ground speed ~ 6.8 km/s of the satellite, the spatial resolution and swath width would be respectively ~ 350 m and 180 km at nadir. The front size of the optics can roughly be estimated for this resolution. Assuming a low earth 600 km orbit, the required focal length (or diameter of F/1 optics) to image a 350 m ground pixel onto the 39 µm microbolometer is ~ 67 mm. The inherent field of view for the 180 km swath is ~ 8.5 deg.

The radiometric calibration is made by means of a mirror rotating between the external view (nadir), an on-board blackbody, and the cold space. The targeted accuracies of temperature measurement is 1 K for a 300 K scene and 2 K for a 200 K scene. The temperature stability of the array is achieved by means of an integrated thermoelectric cooler and precision temperature sensor with PID control. The required stability of the array is ~ 20 mK between calibrations. The thermoelectric cooler is connected to the radiator via a thermal strap. The radiation shield is thermally linked to the cooler so that its temperature remains as stable as the array temperature. The radiometer instrument is thermally decoupled from the platform with insulating washers and insulated with standard MLI. Distributed thermocouples will be used to further stabilize the temperature inside the instrument. Such stabilization is necessary to minimize the background fluctuation detected by the bolometers.

ACKNOWLEDGMENTS

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